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Enhancing PV Panel Performance with Different Types of Phase Change Material (PCM): An Experimental Study

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ABSTRACT

This study examined two solar panels with a high producing capacity of 250 W for performance enhancement utilizing several types of paraffin wax (RT57, RT61, and RT68) connected to the panel's rear surface. Two solar panels (one reference and one combined with PCM; PV-PCM) are used for outdoor tests. The current implementation is made with three types of PCM with a fixed thickness (3 cm) and with different inclination angles of 10°, 20°, 30°, and 40°. According to the results, the PV panels' tops had the maximum temperature spread, while their bottoms showed the lowest variation in temperature. At an inclination angle of 10◦, the temperature on the upper side of the plate is 18.8% higher than the lower side, 14.3%, and 12.2% for PCM1, PCM2, and PCM3, respectively. There is also an improved electrical power output of 16.8% for the PV-PCM panel with 3 cm PCM thickness over the reference panel (PV) with a tilt angle of 40◦. Relatedly, raising the inclination angle from 10◦ to 40◦ improves the Energy efficiency of PV-PCM with a thickness of 3 cm PCM by 10.4%. Finally, using 3 cm thick PCM improves the Energy efficiency of the PV-PCM panel by 17.4% compared to PV with an inclination angle of 30◦.

Keywords:
Panel; PCM; tilt angle; paraffin wax; electrical efficiency

1. Introduction

Panels give electrical energy to the corresponding request after using air energy as an energy input. A substantial amount of solar energy is lost to the atmosphere as heat due to convection and radiation. For numerous purposes, solar photovoltaic (PV) panels are considered one of the most important renewable energy sources [1,2]. Many factors, including the working temperature of cell semiconductors and the amount of incident solar radiation, influence how efficiently solar Solar panels operate. The heat that is absorbed raises the temperature, negatively impacting its output. As a result, as the surface temperature rises, the performance of the PV panel declines [3]. To perform proper thermal control, PCM-mixed thermal systems are employed as passive cooling systems [4].

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Numerous experiments have been conducted recently to manage thermal energy utilizing phase-change materials and reduce the surface temperature of solar panels [5,6]. By melting or solidifying, choosing the right PCM material can store significant heat or cold.

Usually less than 10%, a slight volume shift occurs when PCM melts. Research on the PV performance mixed with PCM was conducted experimentally [7]. According to the results, with the drop in temperature of 7 ◦C, the PV-PCM panel's daily average performance increased by 1.21%. With 3 PCM-Solar panels and two different types of PCM, Chiew *et al.,* [8] conducted an experimental investigation. After 130 minutes, the results showed that the RT-25 kept the temperature over the front surface of the PV panel below 29 °C. Granular GR-40 performed worse at regulating temperature than RT-25. Water-based PV-T and PV/T-PCM panels were used in an experimental implementation by Maghrabie *et al.,* [9] and Kant *et al.,* [10]. The PV/T and PV/T-PCM combinations showed the largest increases in Energy efficiency, 10.66%, and 12.6%, respectively. Several authors conducted an experimental study on a special PV/T/PCM panel using PCM's capric-palmitic fatty acid eutectic [11-17]. The findings showed that the PV/T-PCM panel's thermal efficiency varied from 20% to 25%. This study aims to increase the efficiency of solar panels utilizing different phase-change materials with fixed thicknesses and varied inclination angles. Additionally, when contrasting it with traditional photovoltaic panels, use it as a reference panel (PV).

2. Method

2.1 Experimental Work Set-Up

The experimental setup's photo rig and schematic is displayed in Figure 1 and Figure 2. The setup for the experiment is built in Kirkuk, Iraq. A reference panel (PV) without PCM and another with three different types of PCM (RT-57, RT-61, and RT-65) and designated as PV-PCM, two identical PV panels with a rated power capacity of 250 W for testing all details and properties are shown in Table 1, one PCM-filled container with different varieties of PCM at a constant thickness of 3 cm, and all details and properties are shown in Table 2. The experimental setup consists of the measuring equipment and an adjustable stand. PV systems tilt angle is controlled by an adjustable stand consisting of bars with metal angles on one movable side to adjust the panels' angle. The stand's panels are oriented southward, and the tilt degrees with regard to the horizontal axis are 10°, 20°, 30°, and 40°. The effects of PV panel tilt angle on electrical efficiency and PCM melting during testing are investigated. A 165 cm by 65 cm by 4 cm internal PCM container with a 2 mm thick galvanized sheet construction is worked. Once all of the PCM has melted, the container is positioned behind the PV panel, secured with screws, and sealed with silicone adhesive to prevent leaks. To demonstrate the feasibility of using PCM and to experimentally improve the performance of solar panels, measurements are done of the voltage, current, ambient air temperature, and incident solar radiation intensity. Table 3 presents the details of every device that is being used. Temperatures were recorded at nine separate spots on the plate's surface. T1 through T9, which represent the average temperatures at the locations shown in Figure 3, were thus employed. This will help you comprehend the results section's numerical data even better. Figure 4 shows the types of PCMs mixed with panels.

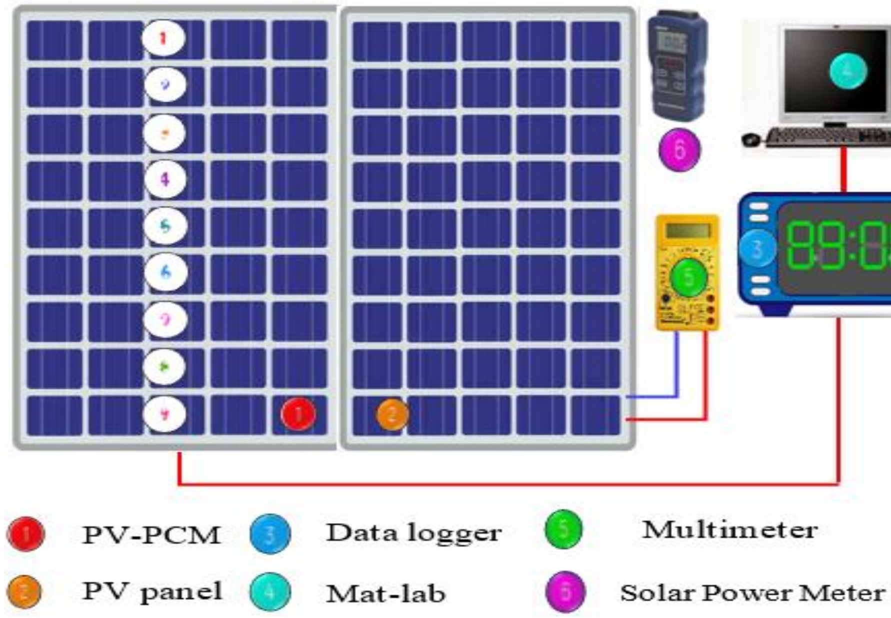

Fig. 1. Schematic of PV and PV PCM panels

Fig. 2. Real Photograph of the experimental rig

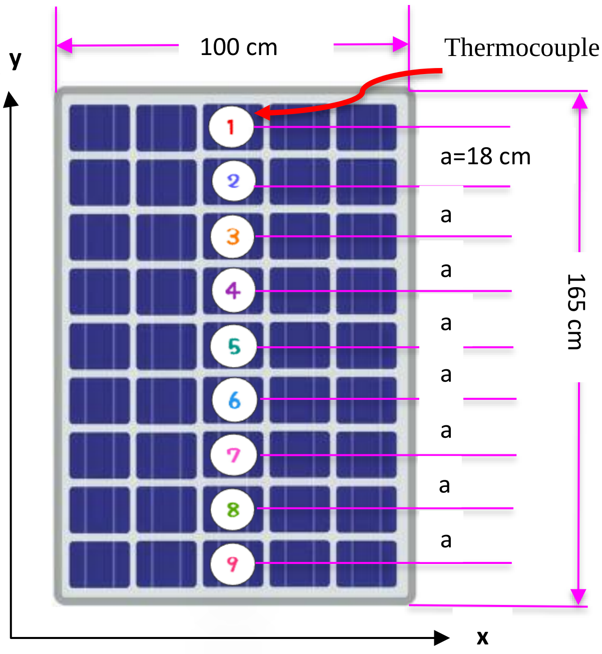

Fig. 3. Temperature distribution schematic of PV panel

Fig. 4. Real photo of PV panel :(A). PV-PCM1, (B) PV-PCM2, (C) PV-PCM3, (D)Back side cover

Table 1
PV Panel Properties [18-20]

Parameter	Specification		
Power	250W	Co-eff. Power	-0.4% / 0K
Open circuit Voltage	37.74V	Co-eff. Voltage	-0.34% / 0K
Short circuit Current	8.74A	Co-eff. Current	+0.005% / 0K
voltage at maximum	30.5V	Weight	18.0Kg
Current at Maximum	8.2A	Dimension	16. 5 x 100 x 4 cm

Table 2
Thermo-Physical Properties of PCMs [21,22]

Parameter	PCM1	PCM2	PCM3
Melting temperature [K]	330	334	338
Solidus density [kg/m^3]	841.32	852.14	860.77
Liquids density[kg/m^3]	757.25	766.11	770.53
Specific heat [J/kg K]	2891	2900	2952
Thermal conductivity [W/m K]	0.00031	0.000305	0.0003

Table 3
Illustrates the measurement error of every piece of apparatus [23]

Measuring Name	Type and uses	Error
Solar power meter	To measure solar irradiation (W/m^2)	±10 (W/m^2)
Flow-meter	To measure volume flowrate (CPM)	±0.1%
Dig. Thermometer	To measure temperature (℃)	±0.5℃
Anemometer	To measure Air Velocity(m/s)	±0.1%

From 09:00 to 16:00, data is gathered every 60 minutes, and for each experiment, the solar radiation intensity, V_{OC}, and I_{SC} for PV panels are reported. These steps are taken in order to determine how well solar panels function under the test conditions.

i. To prevent the accumulation of dust, clean the PV panels before every test.
ii. Verify that the circuit has the capability to measure current and voltage in order to determine the output of electrical power.
iii. To record the sun radiation intensity (S), use a digital solar meter.
iv. Measure the surrounding air temperature with a manometer.
v. To measure ISC and VOCs, set the multimeter to the proper mode.
vi. Check the temperature distribution on the photovoltaic screen's front side every 60 minutes using the thermal sensor.

The electrical efficiency and power capacity are calculated using the following formulas [24,25].

The PV panels' incident power is provided by

$$P_{inc} = S.A \quad (1)$$

where A is the panel area (in [m^2], and S is the incident solar radiation intensity (in [W/m^2]).

In addition, The PV panels' electrical output power (P_{ele}) is calculated by

$$P_{ele} = I.V \quad (2)$$

The formula below can also be used to get the maximum obtained power (P_{max})

$$P_{max} = V_{max}.\ I_{max} \quad (3)$$

where Vmax and Imax are the maximum voltage and current.

The parameter that joins the VOC and ISC to determine the maximum power output from a photovoltaic panel is called the fill factor (FF)

$$\mathrm{FF} = P_{max}\, V_{oc}\, .\, \mathrm{I}_{\mathrm{sc}} \tag{4}$$

The following is the standard equation for calculating a photovoltaic panel's electrical efficiency (η_{ele})

$$\eta_{\mathrm{ele}} = \mathrm{P}_{\mathrm{max}}\, .\, \mathrm{P}_{\mathrm{Inc}} \tag{5}$$

2.2 Uncertainty of Experimental Data

Accurate evaluation was necessary to determine the measured parameters' correctness in this investigation. For each variable (y'), the uncertainty (ε_y) is therefore defined as follows: the uncertainty interval is given after the variable's best value (y) [26].

$$y' = y + \varepsilon_y \tag{6}$$

When y' is the variable being measured, y represents its best value, and the uncertainty is represented by ε_y. The errors in the current experimental data utilized to help the panel's performance are computed using the method from Kline and McClintock [27]. The degree of uncertainty in PV calculations, including electrical power and efficiency (η_{ele}), is significantly influenced by the accuracy of each measured variable, including V, I, and S. Thus, using the least-square fit approach, the uncertainty (ε_y) of the calculated electrical efficiency (η_{ele}) resulting from uncertainties of individual variables was assessed as follows

$$\varepsilon_y = \left[\left(\frac{\partial y}{\partial y_1}\delta y_1\right)^2 + \left(\frac{\partial y}{\partial y_2}\delta y_2\right)^2 + \cdots + \left(\frac{\partial y}{\partial y_n}\delta y_n\right)^2\right]^{\frac{1}{2}} \tag{7}$$

Table 4 shows the experimental instruments' accuracy and maximum uncertainties.

Table 4
Value of uncertainty in computation and measurement

Parameters	Maximum Uncertainty
Electrical efficiency, ηele	±3.24%
Incident radiation, S	±0.8%
Current, I	±0.14%
Voltage, V	±0.06%
Temperature, T	±0.17%
Tilt angle, β	±1.15%

3. Results and Discussion

The effect of using multiple types of PCM (RT-57, RT-61 and RT-65) at a constant thickness to cool photovoltaic panels on their performance is tested experimentally in this article. The effect of using various PCM kinds attached to the PV-PCM panel's back surface at four tilt degrees and a constant thickness on the panel's performance is examined throughout the studies. A pair of identical solar panels, each capable of producing 250 W of power, are examined and installed outside, facing south. PV stands for reference panel, which is one that is directly coupled to one of the three types of PCM containers: PV-PCM1, PV-PCM2, and PV-PCM3. Air in the surrounding environment cools the other panel. Under the same meteorological circumstances, the two panels are investigated simultaneously. To adjust the tilt angle of the PV panels at 10°, 20°, 30°, and 40°, a moveable platform is used to hole the panels.

3.1 Average Ambient Temperature and Average Solar Radiation

Air temperature and radiation are the primary climate variables that impact solar panel performance. To assess the effectiveness of panels, the recorded values of these two parameters are analyzed. Figure 5 shows the average ambient air temperature and the variation in solar intensity during the course of the tests. It is viewed that the sun intensity rises from 541 W/m^2 at 9:00 to 841 W/m^2 at 12:00, when it peaks, and then tends to decrease until 363 W/m^2 at 15:00. In addition, the average outside temperature is around 28 °C at 9:00 and increases gradually to 36–38 °C at noon and 40 °C by 15:00.

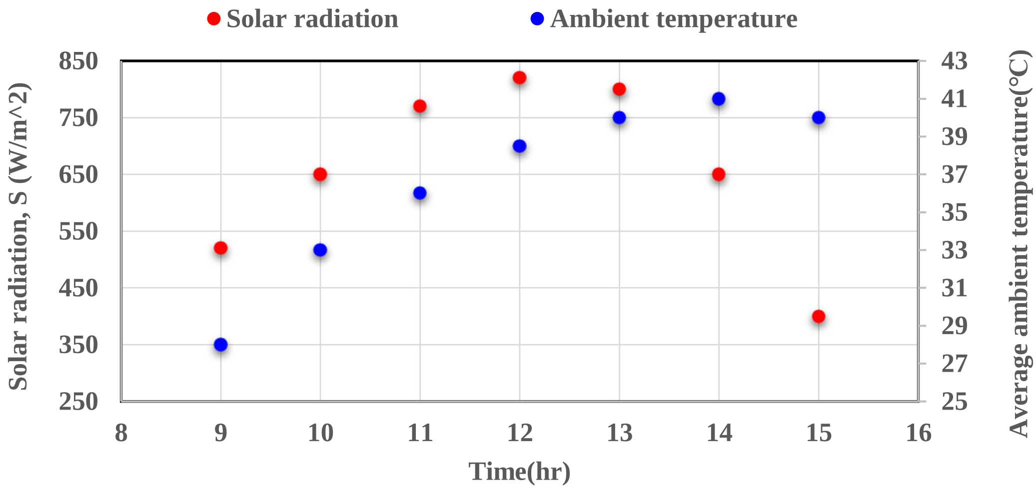

Fig. 5. Average sun radiation and average local temperature (Kirkuk, Iraq)

3.2 PV Panel Temperature Variation

Figure 6 shows how the PCM types (RT-57, RT-61, and RT-65) affect the temperature variation on the front surface of the panel using nine evenly spaced thermal sensors and panel tilt angles of 10, 20, 30, and 40 degrees, at 841 W/m^2. It is observed that increasing the plate inclination angle results in a significant decrease in the surface temperature for all types of PCM. The PV-PCM panel records the maximum temperature variation on its surface when placed at an angle of 10 degrees, while the lower surface temperature is recorded at 40°. This is likely because convection, at small tilt angles, causes very little energy to flow within the PCM [28]. Moreover, the results show that changing the PCM type reduces the plate surface temperature rise from T1 to T9 at all values of inclination angles. For PCM types 1, 2, and 3, the temperature difference between the upper (T9) and lower (T1) sides of the PV panel with an inclination angle of 10^o is 18.18%, 14.3%, and 12.2%, respectively. This confirms that the upper part has less cooling due to the melting of the PCM and sliding downwards, leaving a vacuum in the upper part of the PV-PCM panel.

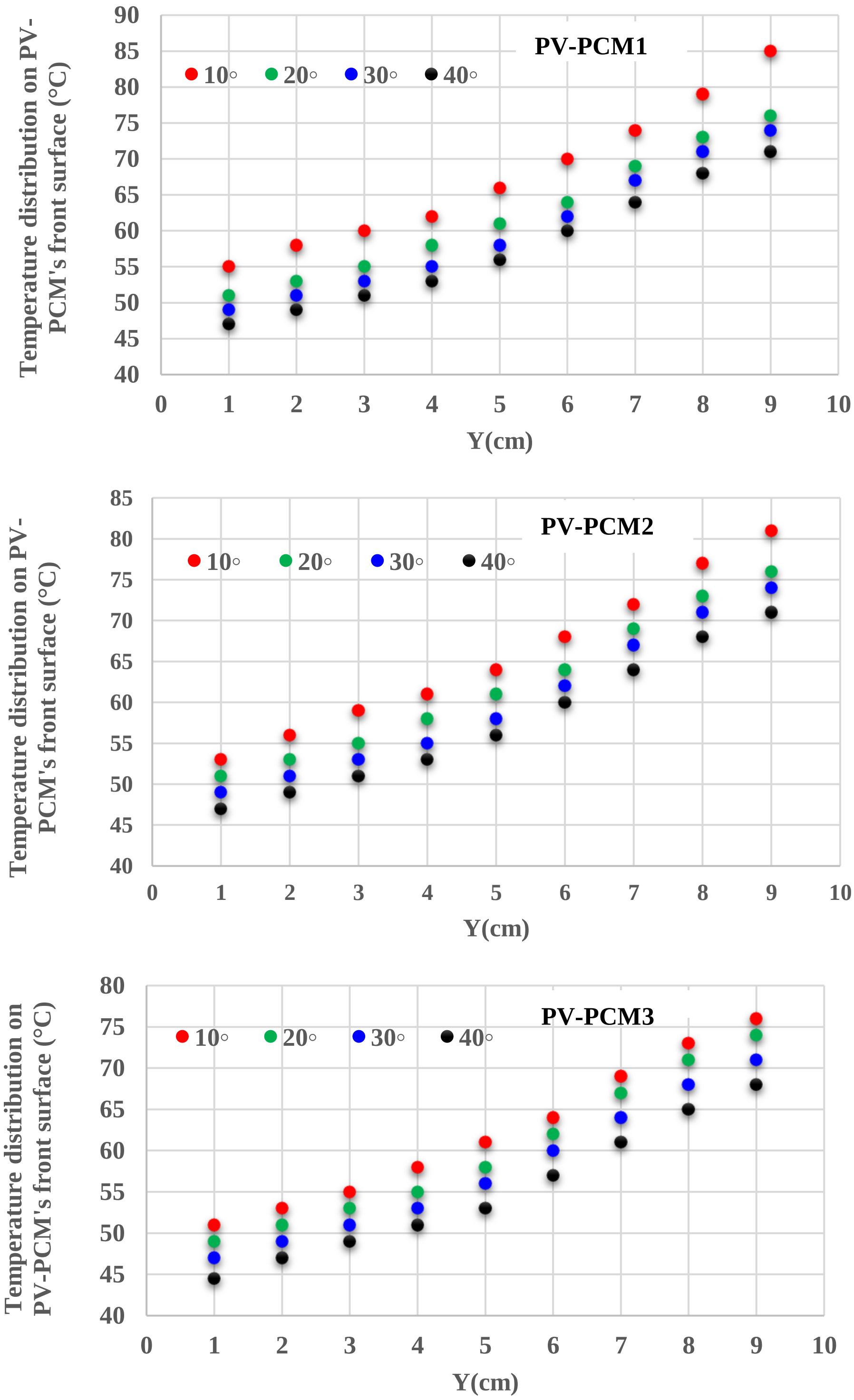

Fig. 6. Temperature distribution for each PCM type on the front face of the PV-PCM panel

Figure 7 illustrates how the temperature variation on the front face of the PV-PCM panel at 841 W/m^2 changes with a change in PCM type at different tilt angles of 10°, 20°, 30°, and 40°. The results of the experiment indicate that the surface temperature of the PV panel may be significantly lowered by changing the kind of PCM on its back surface. Additionally, because of the melting characteristics of using PCM to cool the panel's back side, the front surface temperature at the top side (T9) is higher than the temperature at the bottom side (T1) at PCM1 type by 16.5%, 18.2%, 19.1%, and 19.8% for a tilt angle of 10°, 20°, 30°, and 40°, respectively. The types of PCM used and the angle of panel have a considerable impact on the temperature distribution on the front face of the panel when employing PCM on the back side. The temperature variation on the front surface is not uniform when PCM is used on the rear of the PV panel in a one-volume box. This suggests that each cell has a unique temperature, which has a significant effect on the electrical energy output, the lifetime of the cell, and ultimately the PV panel's lifetime.

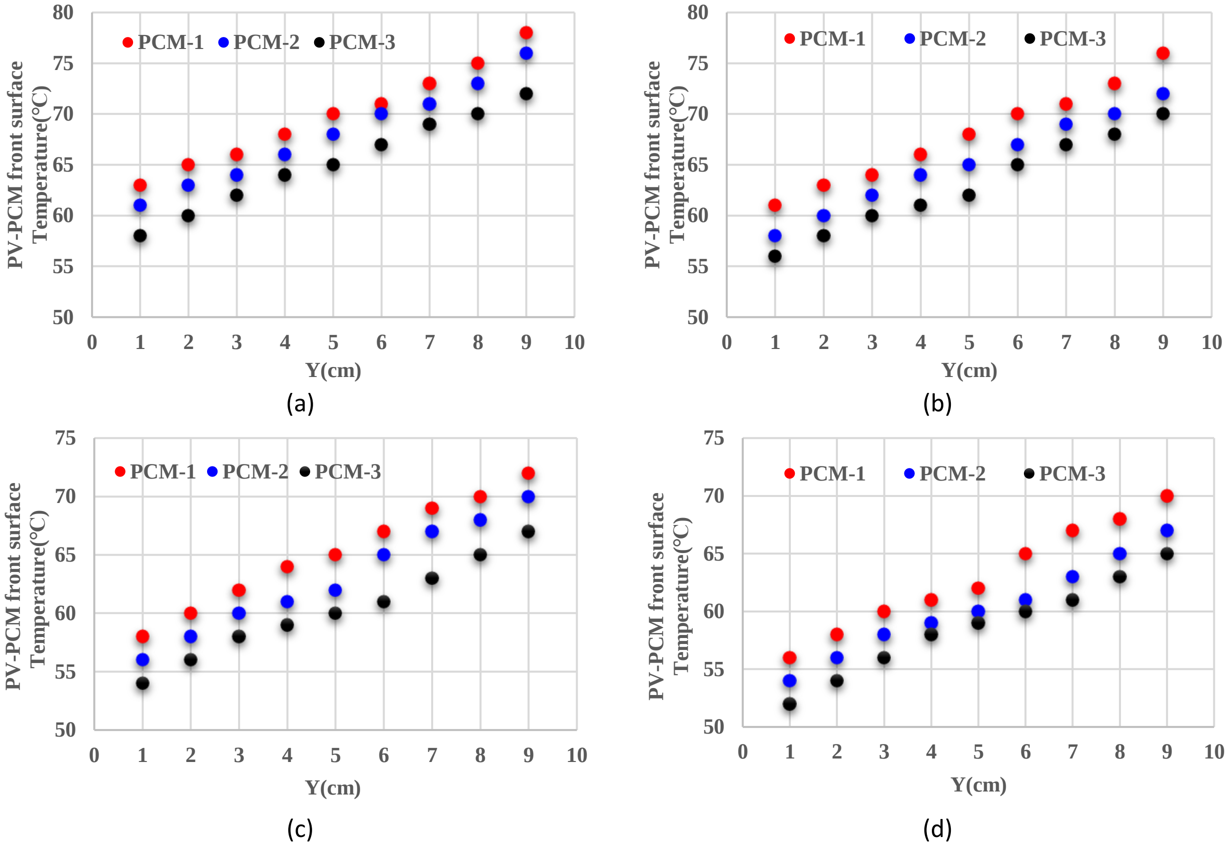

Fig. 7. Temperature distribution at tilt angles of (a) 10◦, (b) 20◦, (c) 30◦, and (d) 40◦ for different types of PCM, on the front surface of PV-PCM panels

3.3 Output of Electrical Power

The power output for PV panels tilted at different angles (10°, 20°, 30°, and 40°) is plotted against the intensity of solar radiation for a 3 cm PCM thickness in Figure 8. Based on the results of the experiment, the reference PV panel's maximum electrical power output is 190.3 W when sun radiation reaches 841 W/m^2, whereas the PV-PCM3 panel's maximum value at the same solar r intensity is 225.47 W when using PV-PCM3 at a 40° tilt angle. This suggests that raising the panel output power corresponds with lowering the panel surface temperature. Furthermore, as solar radiation intensity increases, there is a higher noticeable increase in the electrical power output of the PV panels as a result of adopting PCM for all types of PV panels, compared to reference panels.

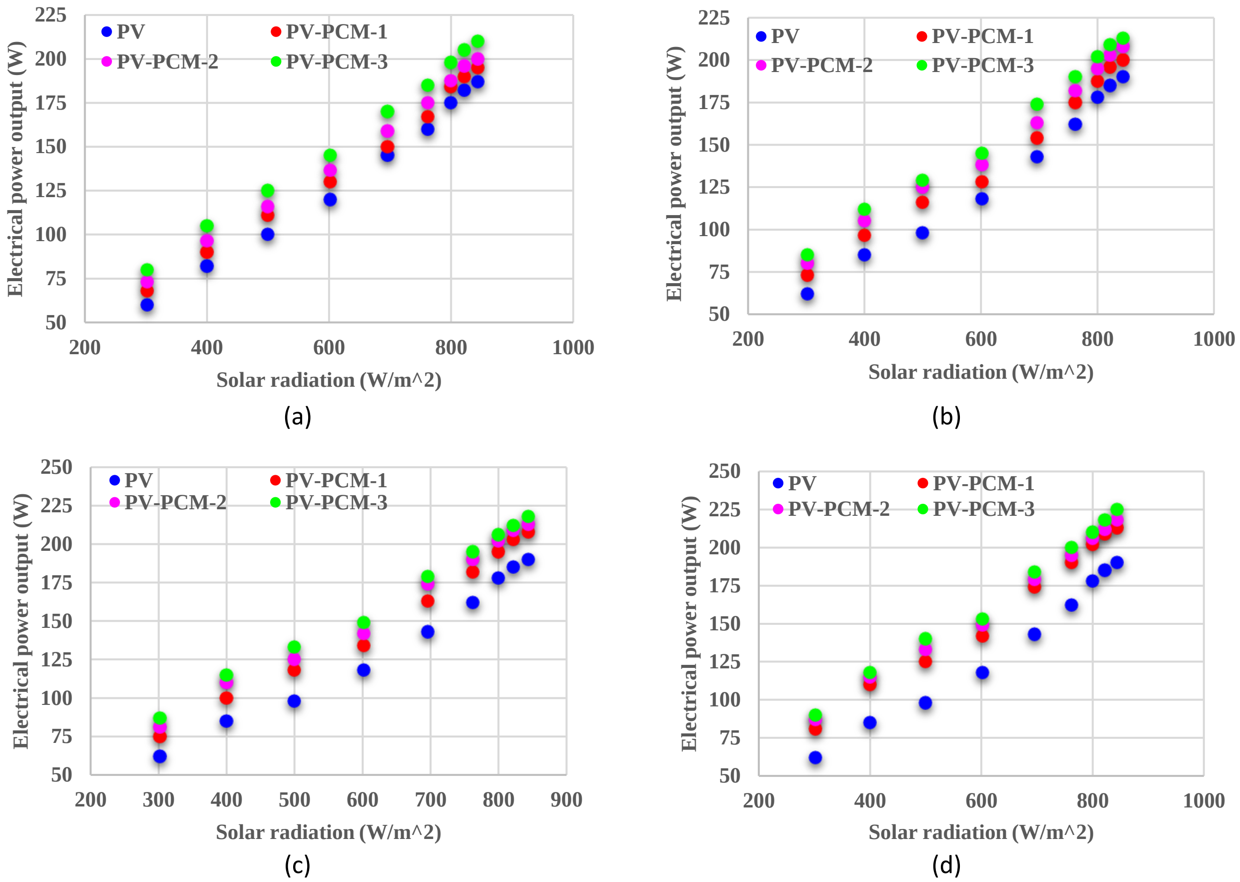

Fig. 8. The electrical power output at tilt angles of (a) 10◦, (b) 20◦, (c) 30◦, and (d) 40◦

3.4 Electrical Efficiency

The shown variation in PV panel performance during the day is due to a similar pattern of variation in both the radiation received and the power supplied.

The variation in PV panel and PVPCM panel electrical efficiency vs sun radiation at various tilt angles (10, 20, 30, and 40 degrees) is shown in Figure 9. The panels are made of PCM panels of different types at every tilt angle, it has been found that the PVPCM panel's efficiency exceeds that of the PV panel.

The PV panel's greatest electrical efficiency at a 40° tilt angle is 13.5% at 841 W/m^2 of solar radiation, according to the data; at the same solar radiation intensity, the PV-PCM panel's maximum electrical efficiency is 15.4%. Furthermore, when solar radiation intensity increases, the increase in thermal efficiency brought about by the use of PV-PCM is diminished for all tilt angle values of panels. Furthermore, both PV panels' maximum thermal efficiency values are maintained at a 40° tilt angle.

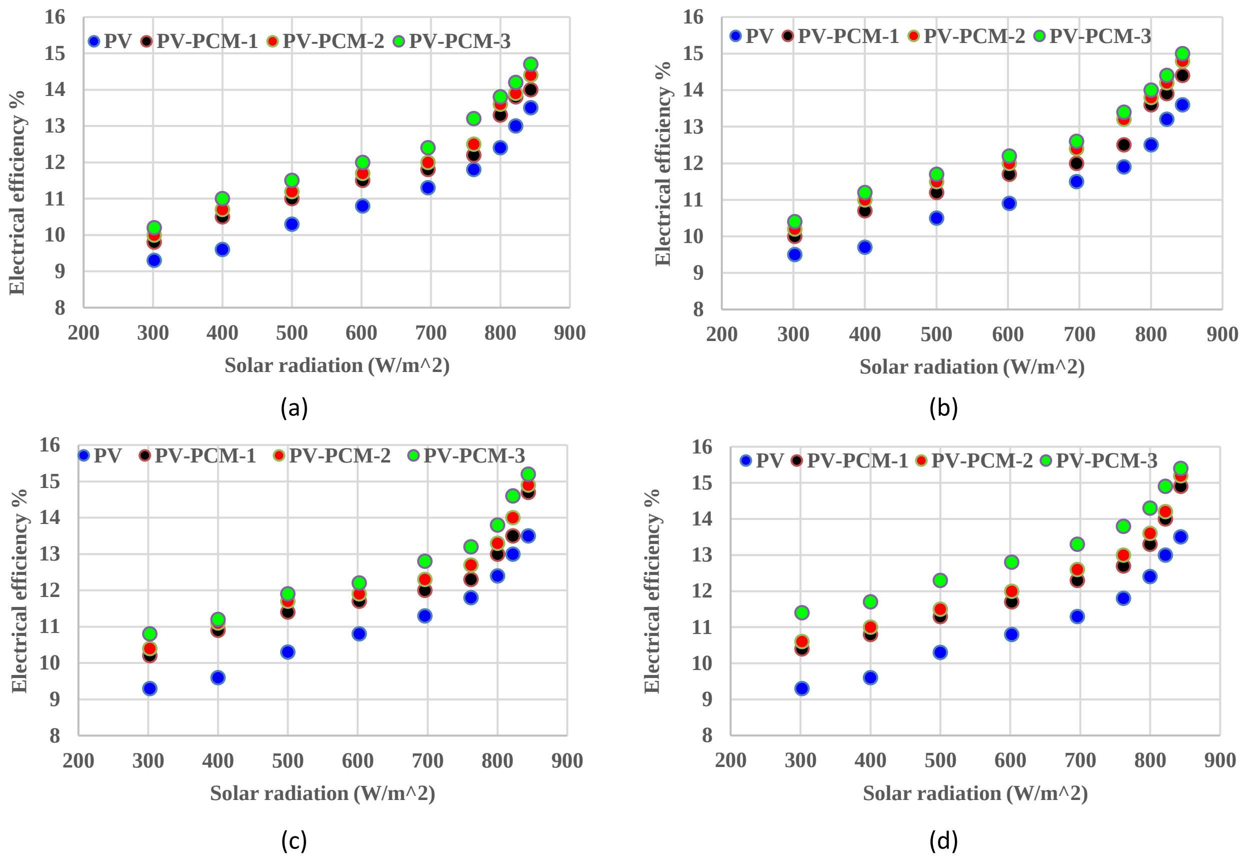

Fig. 9. PV and PV-PCM panel electrical efficiency and solar radiation with angle of (a) 10◦, (b) 20◦, (c) 30◦, and (d) 40◦

Figure 10 displays the mean output power and electrical efficiency variation for PV and PV-PCM panels at various tilt degrees and PCM types. PV panels have an average power of 165 W at a 40◦ tilt angle; in contrast, the PV-PCM panel has an average power of 168.1 W, 175 W, and 205 W at PCM1, PCM2, and PCM3, respectively. Furthermore, 145 W, 151.3 W, 155.1 W, and 165 W are the matching values for panel. At different angle of 10◦, 20◦, 30◦, and 40◦, respectively, those of the PV-PCM3 are 175 W, 184.8 W, 193.1 W, and 205 W. When comparing the PV-PCM3 panel's power output to the PV panel at a 40° tilt angle, these figures show a notable increase of 16.8%. Also, when the PV panels' tilt angle is reduced, their average electrical power output drops. Furthermore, the findings of the experiments indicate that varying PCM kinds and tilt angle greatly improve electrical efficiency. PV-PCM3's electrical efficiency rises by 10.4% when the tilt angle is increased from 10◦ to 40◦. Finally, utilizing PCM3 increases the PV-PCM panel's efficiency by 17.4% when compared to a PV panel at a tilt angle of 40◦. Table 5 shows a comparison of the percentage improvement of the results of this study with the results of previous studies in terms of electrical efficiency and power.

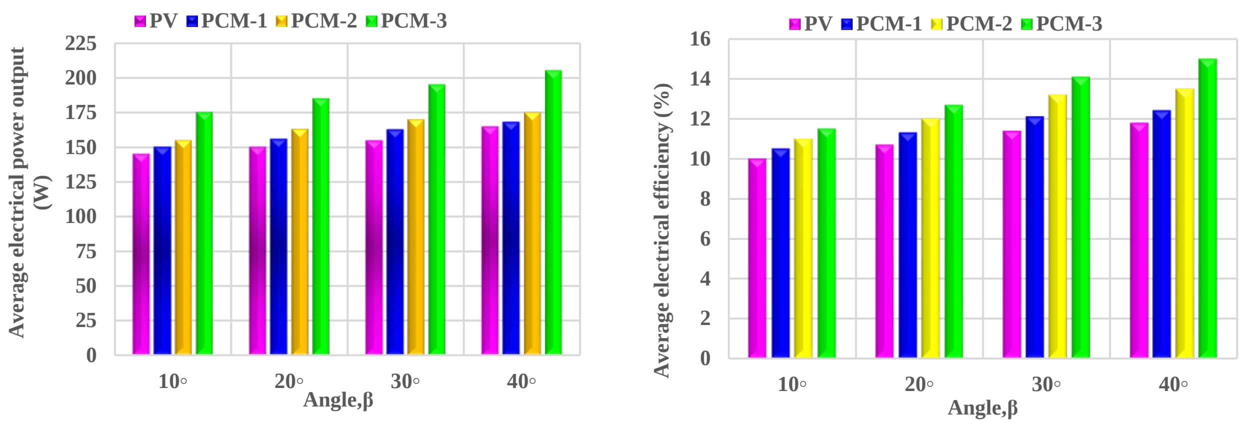

Fig. 10. (a) Average output power; (b) Mean electrical efficiency of PV and PV-PCM panels at various PCM kinds

Table 5
Comparing the results of this study with those of previous studies

Ref.	Location	Power Enhancement (%)	Electrical Efficiency. Improvement (%)
Hachem *et al.,* [29]	Lebanon	7-7.4%	5.8%
Stropnik and Stritih [30]	Slovenia	9-9.2%	1.1% –2.8%
Agyekum *et al.,* [31]	Russia	11-11.33%	5.15%
Wongwuttanasatian *et al.,* [32]	Thailand	3.5-3.6%	5.3%
Atkin and Farid [33]	New Zealand	-----	12.97%
Tan *et al.,* [34]	Australia	3.4-3.44%	5.33-5.39%
Lu *et al.,* [35]	Laboratory solar	-----	10%-12%
Current study	Iraq	9%-15%	12%-18%

4. Conclusion

This work experimentally implements the impact of several PCM types (RT57, RT61, and RT68) on PV panel cooling on PV performance. Installed outdoors and oriented southward are two identical photovoltaic panels. One PV panel is directly mounted on top of a PCM container, known as the PV-PCM. The reference panel is the second photovoltaic panel, which is cooled by the surrounding ambient air. In conclusion, the PV panel's output power and electrical efficiency are improved when PCM is incorporated on the rear side, which lowers the panel temperature distribution. It is discovered that the upper portion of the PV-PCM panel maintains the highest temperature, which is explained in detail by using nine thermocouples to measure the temperature variation on the panel's surface. Similarly, for PCM1, PCM2, and PCM3, the temperature on the pane's upper side (T9) is approximately 18.18%, 14.3%, and 12.2% higher than the bottom side (T1) at a tilt angle of 10^{o}. This demonstrates that there is less cooling in the upper portion of the PV-PCM panel as a result of the PCM melting and sliding downward, creating a vacuum there. When compared to a PV panel at a tilt angle of 40°, the power output of the PV-PCM panel with a 3 cm PCM is 16.8% higher. Furthermore, when compared to 10◦, 20◦, and 30◦, the tilt angle of 40◦ performs well in every situation. Increasing the tilt angle and utilizing different types of PCM also greatly enhance electricity efficiency. When the angle varies between (10◦ to 40◦), the electrical efficiency of PV-PCM at 3 cm thickness improves by 10.4%. Last but not least, employing PCM with a 3 cm thickness raises the PV-PCM panel's efficiency over the PV reference panel by 17.4%.

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References

[1] Salameh, Tareq, Polamarasetty P. Kumar, A. G. Olabi, Khaled Obaideen, Enas Taha Sayed, Hussein M. Maghrabie, and Mohammad Ali Abdelkareem. "Best battery storage technologies of solar photovoltaic systems for desalination plant using the results of multi optimization algorithms and sustainable development goals." *Journal of Energy Storage* 55 (2022): 105312. https://doi.org/10.1016/j.est.2022.105312

[2] Maghrabie, Hussein M., Mohammad Ali Abdelkareem, Khaled Elsaid, Enas Taha Sayed, Ali Radwan, Hegazy Rezk, Tabbi Wilberforce, Ahmed G. Abo-Khalil, and A. G. Olabi. "A review of solar chimney for natural ventilation of residential and non-residential buildings." *Sustainable Energy Technologies and Assessments* 52 (2022): 102082. https://doi.org/10.1016/j.seta.2022.102082

[3] Salem Ahmed, M., A. S. A. Mohamed, and Hussein M. Maghrabie. "Performance evaluation of combined photovoltaic thermal water cooling system for hot climate regions." *Journal of Solar Energy Engineering* 141, no. 4 (2019): 041010. https://doi.org/10.1115/1.4042723

[4] Maghrabie, Hussein M., A. S. A. Mohamed, and M. Salem Ahmed. "Experimental investigation of a combined photovoltaic thermal system via air cooling for summer weather of Egypt." *Journal of Thermal Science and Engineering Applications* 12, no. 4 (2020): 041022. https://doi.org/10.1115/1.4046597

[5] Alami, Abdul Hai, Hussein M. Maghrabie, Mohammad Ali Abdelkareem, Enas Taha Sayed, Zena Yasser, Tareq Salameh, S. M. A. Rahman, Hegazy Rezk, and A. G. Olabi. "Potential applications of phase change materials for batteries' thermal management systems in electric vehicles." *Journal of Energy Storage* 54 (2022): 105204. https://doi.org/10.1016/j.est.2022.105204

[6] Chiew, J., C. S. Chin, W. D. Toh, Z. Gao, and J. Jia. "Thermal state-of-expansion or melting of phase change material based heat sink for underwater battery power system." *Journal of Energy Storage* 26 (2019): 100956. https://doi.org/10.1016/j.est.2019.100956

[7] Algarni, Mohammed, Mashhour A. Alazwari, and Mohammad Reza Safaei. "Optimization of nano-additive characteristics to improve the efficiency of a shell and tube thermal energy storage system using a hybrid procedure: DOE, ANN, MCDM, MOO, and CFD modeling." *Mathematics* 9, no. 24 (2021): 3235. https://doi.org/10.3390/math9243235

[8] Chiew, J., C. S. Chin, W. D. Toh, Z. Gao, and J. Jia. "Low-temperature macro-encapsulated phase change material based thermal energy storage system without air void space design." *Applied Thermal Engineering* 141 (2018): 928-938. https://doi.org/10.1016/j.applthermaleng.2018.06.060

[9] Maghrabie, Hussein, Ahmed Mohamed, Amany Fahmy, and Ahmed A Abdel Samee. "Performance augmentation of PV panels using phase change material cooling technique: A review." *SVU-International Journal of Engineering Sciences and Applications* 2, no. 2 (2021): 1-13. https://doi.org/10.21608/svusrc.2021.87202.1013

[10] Kant, Karunesh, Amritanshu Shukla, Atul Sharma, and Pascal Henry Biwole. "Heat transfer studies of photovoltaic panel coupled with phase change material." *Solar Energy* 140 (2016): 151-161. https://doi.org/10.1016/j.solener.2016.11.006

[11] Pichandi, Ramanan, Kalidasa Murugavel Kulandaivelu, Karthick Alagar, Hari Kishan Dhevaguru, and Suriyanarayanan Ganesamoorthy. "Performance enhancement of photovoltaic module by integrating eutectic inorganic phase change material." *Energy Sources, Part A: Recovery, Utilization, and Environmental Effects* (2020): 1-18. https://doi.org/10.1080/15567036.2020.1817185

[12] Huang, M. J., P. C. Eames, and Brian Norton. "Phase change materials for limiting temperature rise in building integrated photovoltaics." *Solar Energy* 80, no. 9 (2006): 1121-1130. https://doi.org/10.1016/j.solener.2005.10.006

[13] Preet, Sajan, Brij Bhushan, and Tarun Mahajan. "Experimental investigation of water based photovoltaic/thermal (PV/T) system with and without phase change material (PCM)." *Solar Energy* 155 (2017): 1104-1120. https://doi.org/10.1016/j.solener.2017.07.040

[14] Basri, Mahamad Hisyam Mahamad, Yusli Yaakob, Zulkhairi Kamaruzaman, Fairosidi Idrus, Norasikin Hussin, and Idris Saad. "Heat Pipe as a Passive Cooling Device for PV Panel Performance Enhancement." *Journal of Advanced Research in Applied Sciences and Engineering Technology* 28, no. 2 (2022): 190-198. https://doi.org/10.37934/araset.28.2.190198

[15] Hilo, Ali, Abd Rahim Abu Talib, Sadeq Rashid Nfawa, Mohamed Thariq Hameed Sultan, Mohd Faisal Abdul Hamid, and M. I. Nadiir Bheekhun. "Heat Transfer and Thermal Conductivity Enhancement using Graphene Nanofluid: A Review." *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences* 55, no. 1 (2019): 74-87.

[16] Alous, Salaheldin, Muhammet Kayfeci, and Ali Uysal. "Experimental study about utilization of MWCNTs and graphene nanoplatelets water-based nanofluids in flat non-concentrating PVT systems." *Thermal Science* 25, no. 1

Part B (2021): 477-489. https://doi.org/10.2298/TSCI190521337A
[17] Shenouda, R., M. S. Abd-Elhady, and H. A. Kandil. "A review of dust accumulation on PV panels in the MENA and the Far East regions." *Journal of Engineering and Applied Science* 69, no. 1 (2022): 8. https://doi.org/10.1186/s44147-021-00052-6
[18] Browne, Maria C., Declan Quigley, Hanna R. Hard, Sarah Gilligan, Nadja C. C. Ribeiro, Nicholas Almeida, and Sarah J. McCormack. "Assessing the thermal performance of phase change material in a photovoltaic/thermal system." *Energy Procedia* 91 (2016): 113-121. https://doi.org/10.1016/j.egypro.2016.06.184
[19] Jasim, Qusay Kamil. "Effect of The Different Types of Dust on The Performance of Photovoltaic Panels in Iraq." *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences* 100, no. 3 (2022): 1-10. https://doi.org/10.37934/arfmts.100.3.110
[20] Jasim, Qusay Kamil. "Studying the Effect of Cooling Methods on the Performance of Solar Cells." *International Journal of Heat & Technology* 41, no. 1 (2023): 265-270. https://doi.org/10.18280/ijht.410130
[21] Essa, Essa Ahmed, Qusay Kamil, and Noah Mohmmed. "Enhancement of evaporative cooling system in a green-house by geothermal energy." *Open Engineering* 12, no. 1 (2022): 752-759. https://doi.org/10.1515/eng-2022-0362
[22] Hasan, Hiba A., and Ihsan Y. Hussain. "Simulation and testing of thermal performance enhancement for cascade thermal energy storage system by using metal foam." *International Journal of Mechanical & Mechatronics Engineering IJMME-IJENS* 18, no. 5 (2018): 106-117.
[23] Kamil, Qusay, and Najim Abd. "Thermal performance of radiant floor cooling with phase change material for energy-efficient buildings." *Open Engineering* 14, no. 1 (2024): 20220502. https://doi.org/10.1515/eng-2022-0502
[24] Maghrabie, Hussein M., A. S. A. Mohamed, Amany M. Fahmy, and Ahmed A. Abdel Samee. "Performance enhancement of PV panels using phase change material (PCM): An experimental implementation." *Case Studies in Thermal Engineering* 42 (2023): 102741. https://doi.org/10.1016/j.csite.2023.102741
[25] Cui, Yuanlong, Jie Zhu, Fan Zhang, Yiming Shao, and Yibing Xue. "Current status and future development of hybrid PV/T system with PCM module: 4E (energy, exergy, economic and environmental) assessments." *Renewable and Sustainable Energy Reviews* 158 (2022): 112147. https://doi.org/10.1016/j.rser.2022.112147
[26] Schenck, Hilbert, and P. D. Richardson. *Theories of Engineering Experimentation*. McGraw-Hill, 1972.
[27] Kline, Stephen J., and F. A. McClintock. "Describing uncertainties in single-sample experiments." *Mechanical Engineering* 75 (1963): 3-8.
[28] Khanna, Sourav, K. S. Reddy, and Tapas K. Mallick. "Performance analysis of tilted photovoltaic system integrated with phase change material under varying operating conditions." *Energy* 133 (2017): 887-899. https://doi.org/10.1016/j.energy.2017.05.150
[29] Hachem, Farouk, Bakri Abdulhay, Mohamad Ramadan, Hicham El Hage, Mostafa Gad El Rab, and Mahmoud Khaled. "Improving the performance of photovoltaic cells using pure and combined phase change materials-Experiments and transient energy balance." *Renewable Energy* 107 (2017): 567-575. https://doi.org/10.1016/j.renene.2017.02.032
[30] Stropnik, Rok, and Uroš Stritih. "Increasing the efficiency of PV panel with the use of PCM." *Renewable Energy* 97 (2016): 671-679. https://doi.org/10.1016/j.renene.2016.06.011
[31] Agyekum, Ephraim Bonah, Seepana PraveenKumar, Naseer T. Alwan, Vladimir Ivanovich Velkin, and Tomiwa Sunday Adebayo. "Experimental study on performance enhancement of a photovoltaic module using a combination of phase change material and aluminum fins-exergy, energy and economic (3E) analysis." *Inventions* 6, no. 4 (2021): 69. https://doi.org/10.3390/inventions6040069
[32] Wongwuttanasatian, T., T. Sarikarin, and A. J. S. E. Suksri. "Performance enhancement of a photovoltaic module by passive cooling using phase change material in a finned container heat sink." *Solar Energy* 195 (2020): 47-53. https://doi.org/10.1016/j.solener.2019.11.053
[33] Atkin, Peter, and Mohammed M. Farid. "Improving the efficiency of photovoltaic cells using PCM infused graphite and aluminium fins." *Solar Energy* 114 (2015): 217-228. https://doi.org/10.1016/j.solener.2015.01.037
[34] Tan, Lippong, Abhijit Date, Gabriel Fernandes, Baljit Singh, and Sayantan Ganguly. "Efficiency gains of photovoltaic system using latent heat thermal energy storage." *Energy Procedia* 110 (2017): 83-88. https://doi.org/10.1016/j.egypro.2017.03.110
[35] Lu, Wei, Zhishan Liu, Jan-Frederik Flor, Yupeng Wu, and Mo Yang. "Investigation on designed fins-enhanced phase change materials system for thermal management of a novel building integrated concentrating PV." *Applied Energy* 225 (2018): 696-709. https://doi.org/10.1016/j.apenergy.2018.05.030